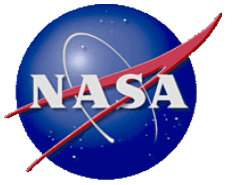
National Aeronautics and Space Administration



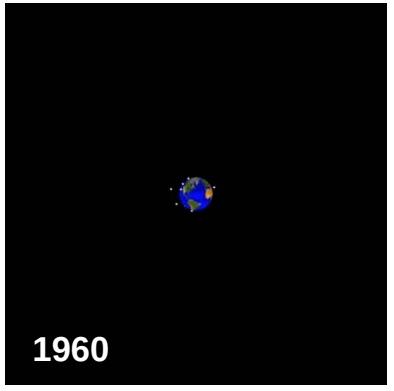
Characterizing the Space Debris Environment with a Variety of SSA Sensors

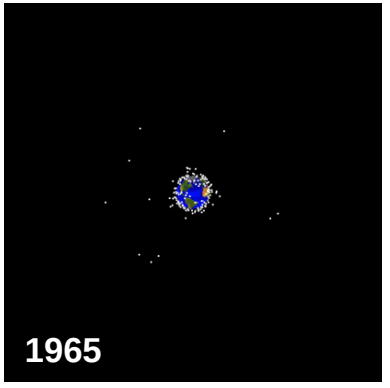
Gene Stansbery

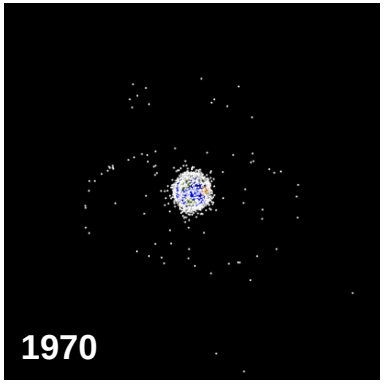
NASA Orbital Debris Program Office
Lyndon B. Johnson Space Center

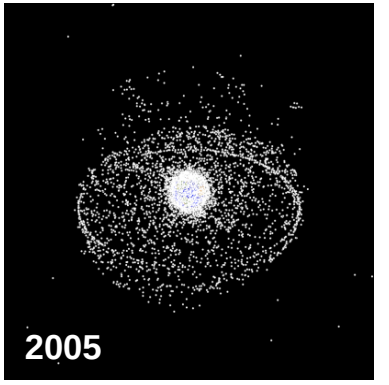
July 2010

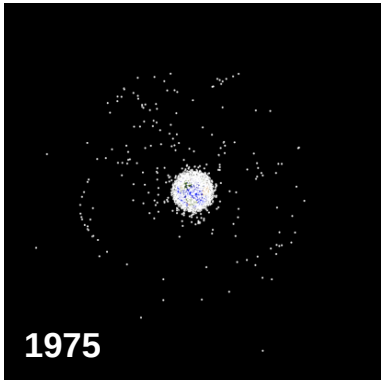
Growth of the Satellite Population

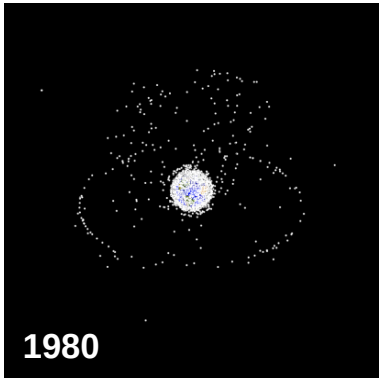


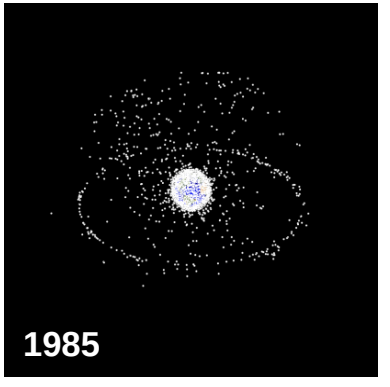


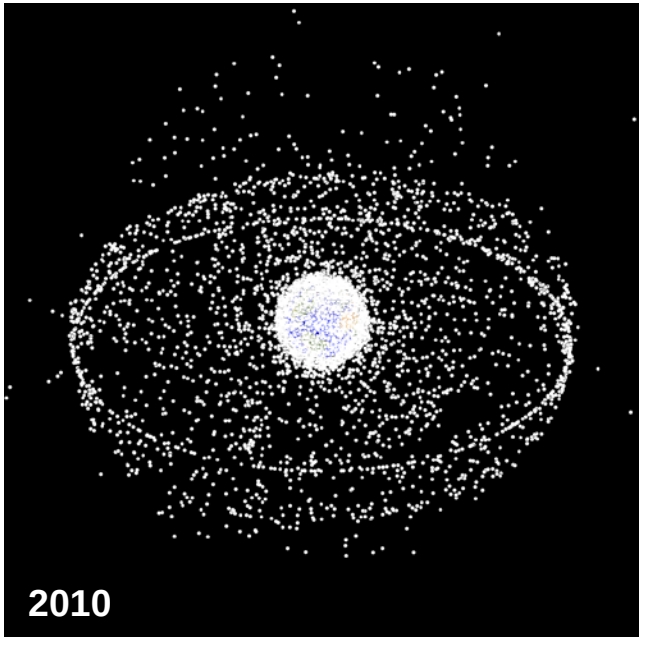


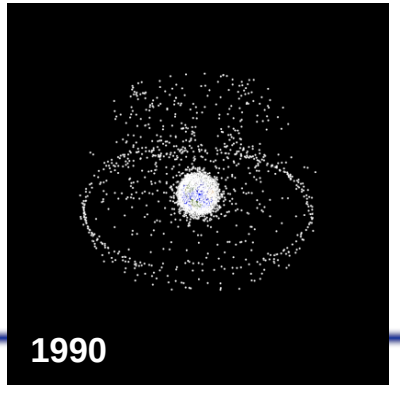


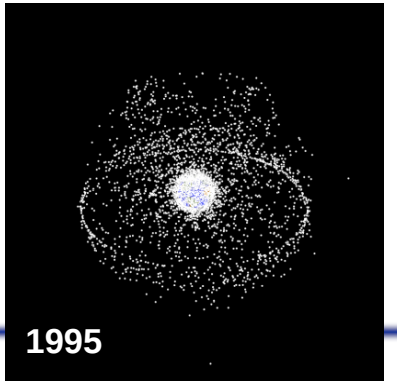


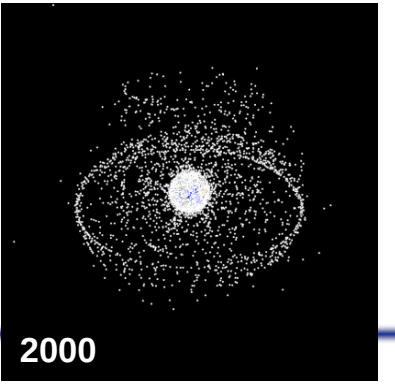






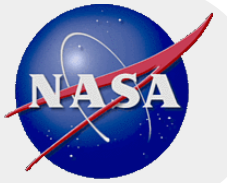






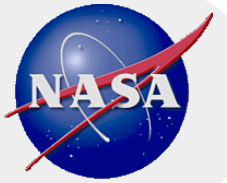
94% of Tracked Object Population are Debris

Space Situational Awareness



- **The term ‘Space Situational Awareness’ has many definitions, but fundamentally it means knowing all there is to know about objects in space.**
- **For space debris, this includes**
  - **Environment definition, distribution of debris**
    - Number
    - Size
    - Orbits
  - **Physical properties**
    - Size
    - Shape
    - Material composition
    - Drag characteristics

Space Situational Awareness (cont.)



- **For space debris, this includes**
  - **Mitigation information**
    - Source
    - Fragmentation cause
    - Collision potential

US Space Surveillance Network (SSN)

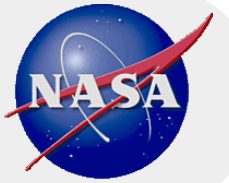
- Radar
- Optical Telescope

LSSC = Lincoln Space Surveillance Center
(Millstone, Haystack, HAX)
AMOS = AFRL Maui Optical & Super-computing Site
AFSSS = Air Force Space Surveillance System
MOSS = Moron Optical Space Surveillance
MSX/SBV = Mid-Course Space Experiment/Space Based Visible

Discovery & Environment Definition

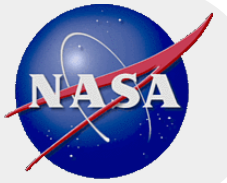
- **Must initially detect, or statistically sample the number and distribution of debris**
- **Implies sensors with large collecting areas**
  - **Air Force Space Surveillance System (formerly NAVSPASUR)**
    - New upgraded system in planning
  - **Phased array radars that routinely erect detection fences**
    - Eglin
    - Cobra Dane
    - Cavalier
  - **High sensitivity/High frequency radars for small debris**
    - Haystack – to 5 mm
    - Goldstone – to 2 mm
  - **GEODSS for high altitude**
  - **New wide field-of-view optical sensors in development**
    - Pan-STARRS

Follow Up Orbit & Source (Parent Body) Definition



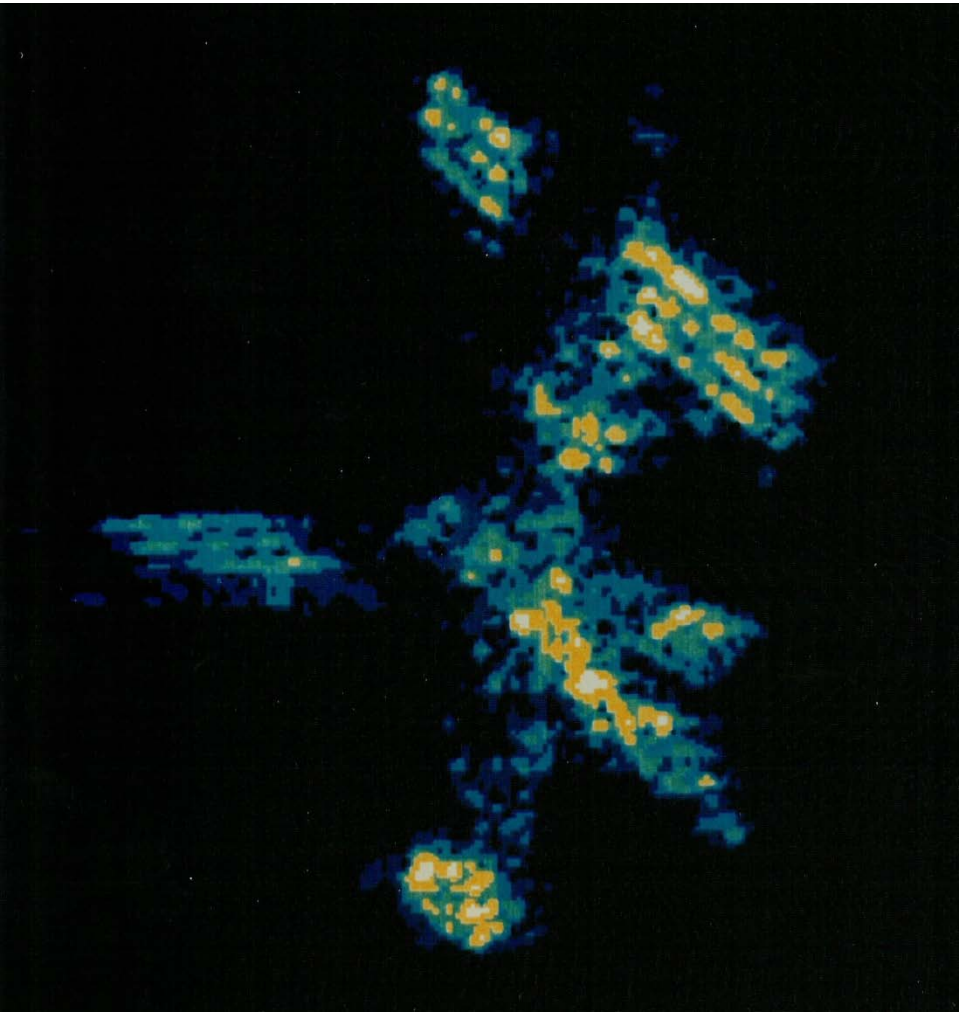
- **Once Discovery is made, follow-up observations refine the orbit & eventually the debris is cataloged**
  - **Indentifying the parent body part of cataloging process**
- **Enables future conjunction assessments**
- **Not possible for small debris**
  - **Sensitivity limits of most SSN sensors**
    - 10 cm for most of the SSN
    - 5 cm for Cobra Dane
    - 2 cm at low altitudes for future upgraded AFSSS
    - 1 m at geosynchronous altitudes
  - **Large numbers of small objects**
    - ~500,000 1-cm & larger debris in low Earth orbit

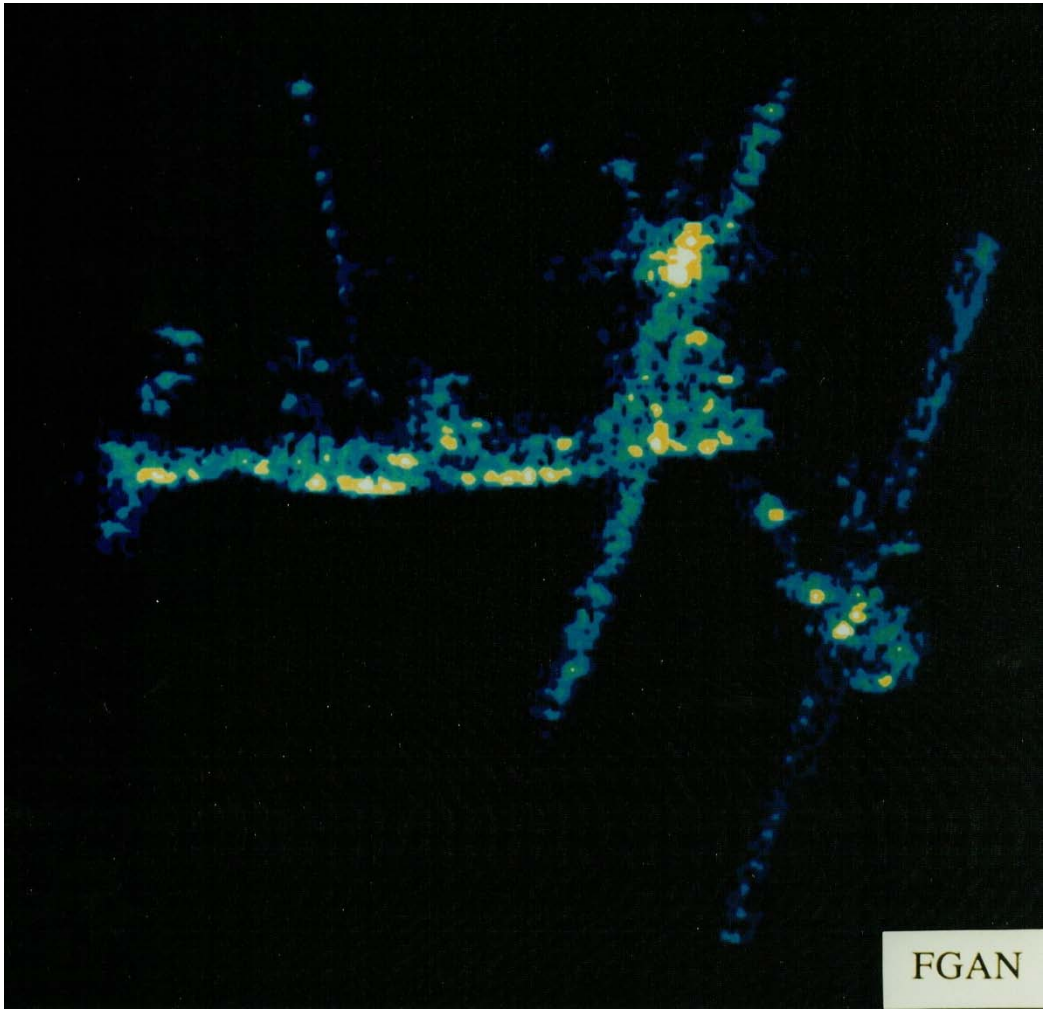
Physical Properties



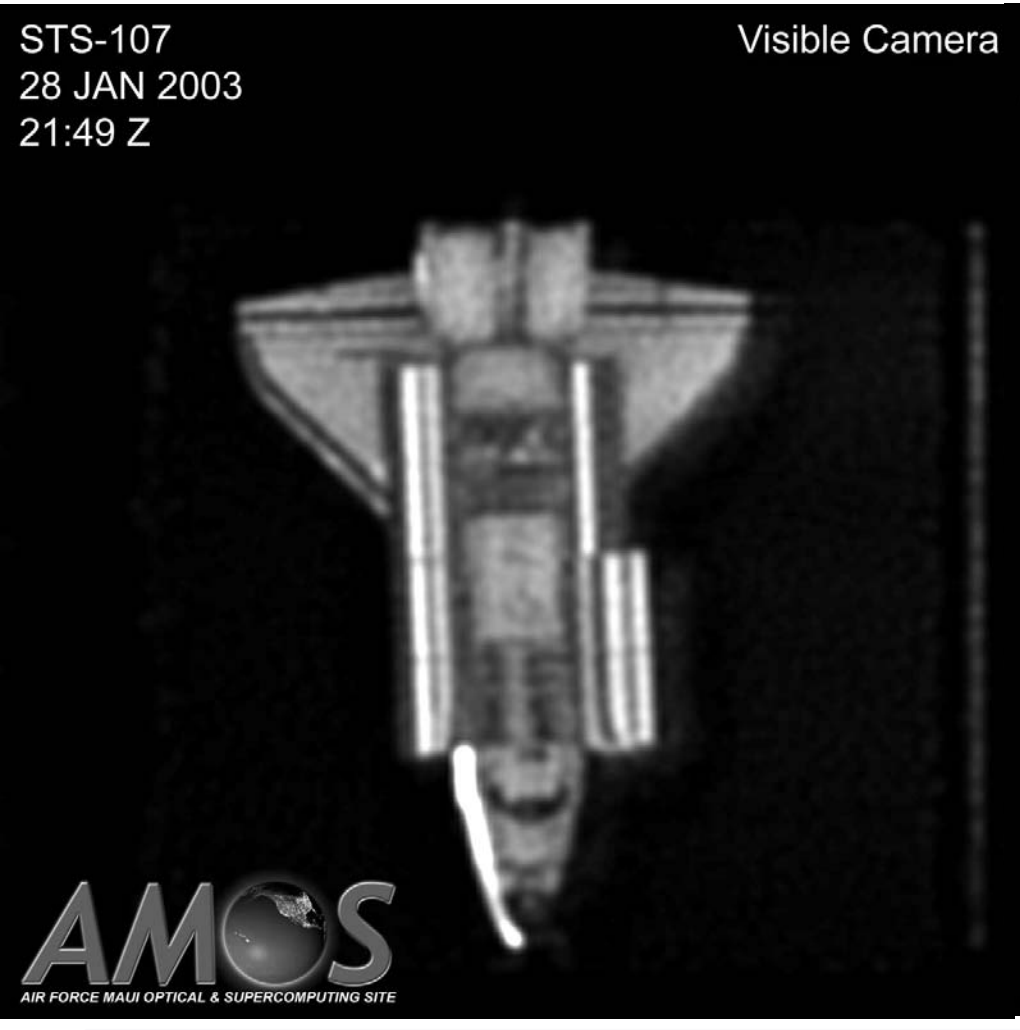
- **Imaging**
  - **Only for large objects**
  - **Sometimes used to look for the cause of a fragmentation**
  - **Radar**
    - Haystack – up grading to HUSIR
    - HAX (Haystack Auxiliary)
    - ALCOR (ARPA-Lincoln C-band Observables Radar)
    - MMW (Mili-Meter Wave)
    - FGAN/TIRA (non US SSN)
  - **Optical**
    - AMOS/AEOS (Air Force Maui Optical Station/Advanced Electro-Optical System)

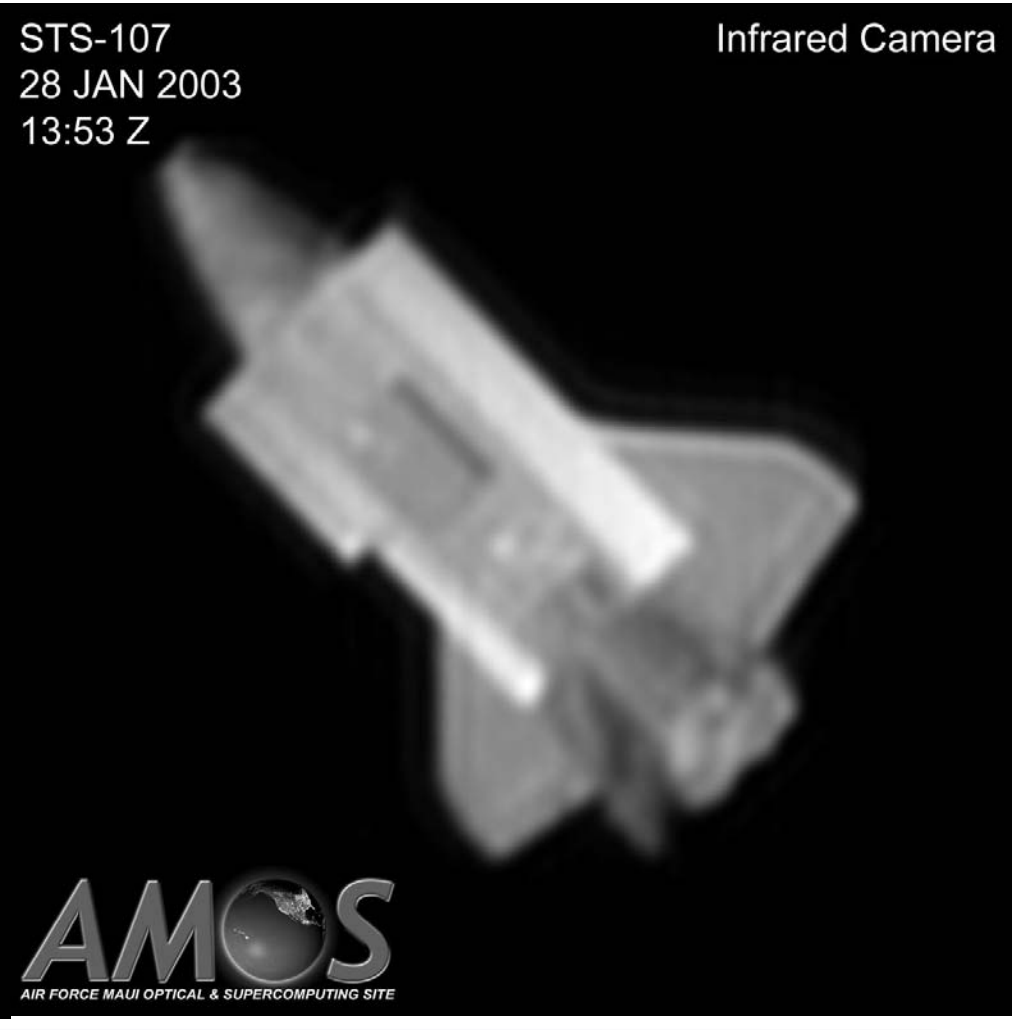
Imaging Sensors - Radar



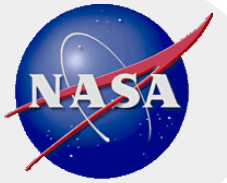


Imaging Sensors - Optical



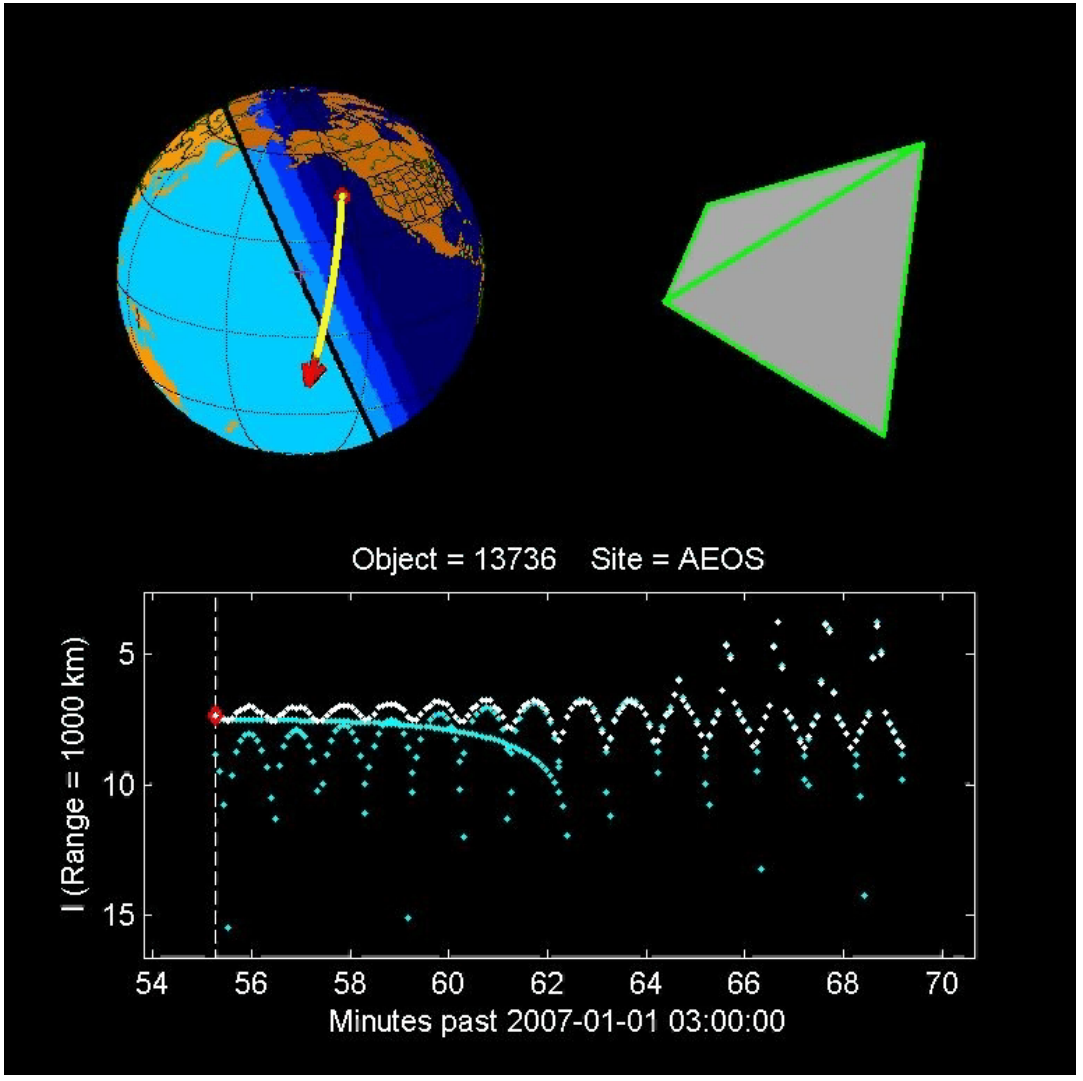


Physical Properties



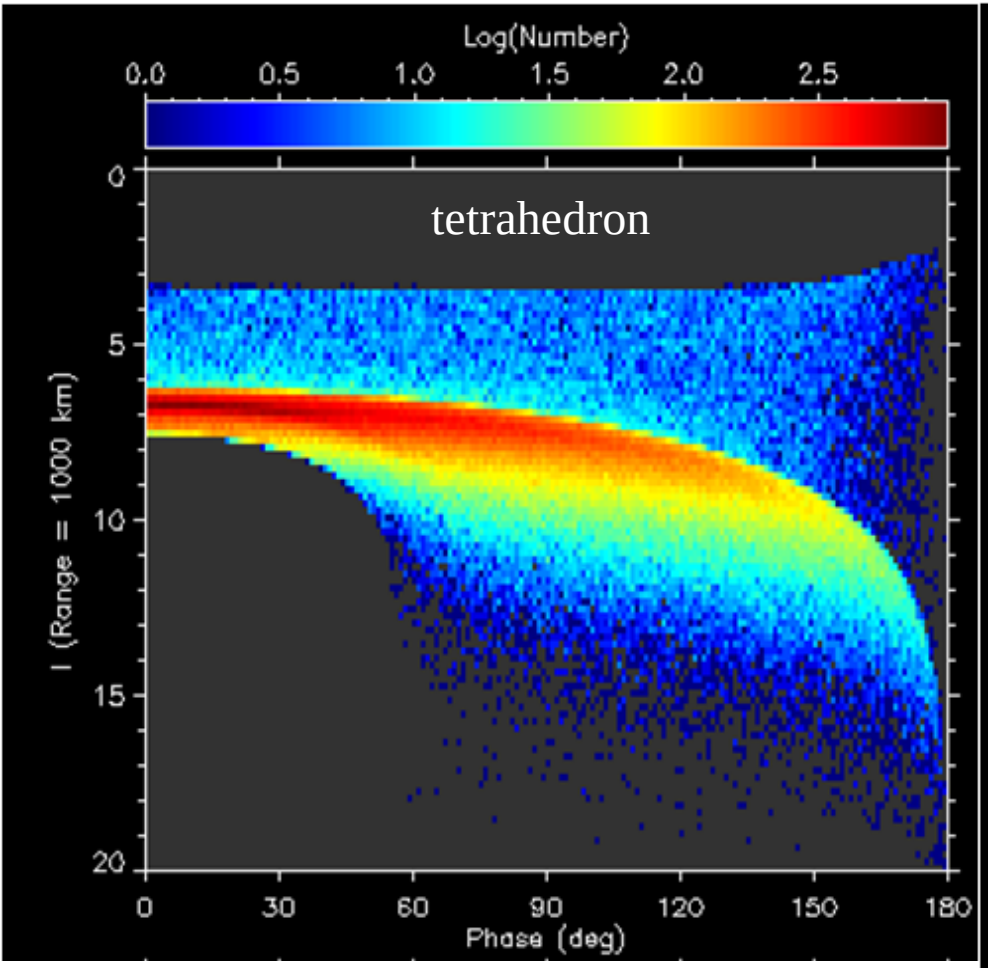
- **Non - Imaging**
  - **Shape**
    - Optical – Light curve analysis
    - Radar – Polarization
      - Spheres
      - Dipoles
  - **Material compostion**
    - Optical – spectral analysis

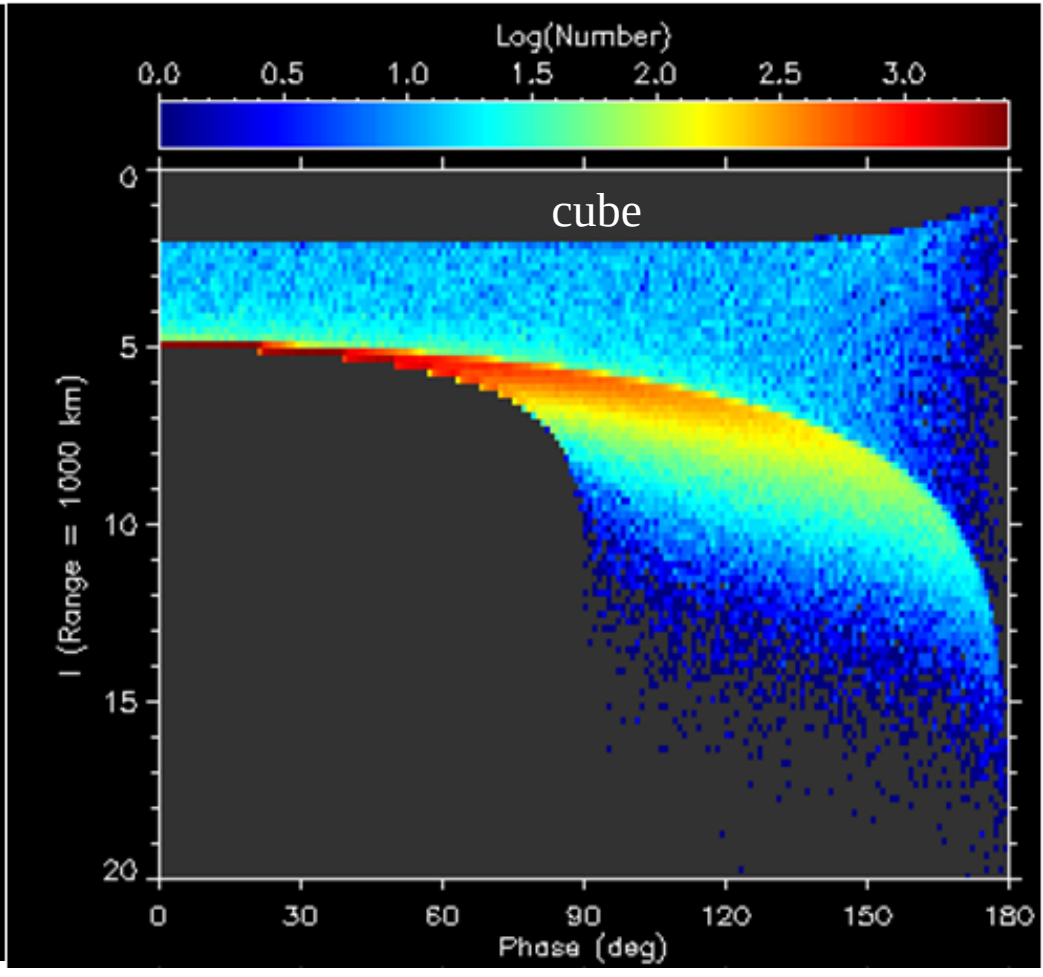
Optical Shape Analysis



Courtesy – Doyle Hall

Optical Shape Analysis

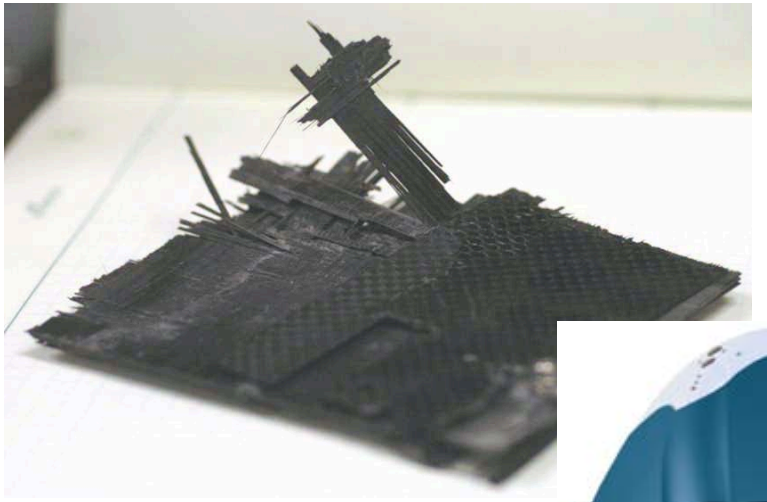


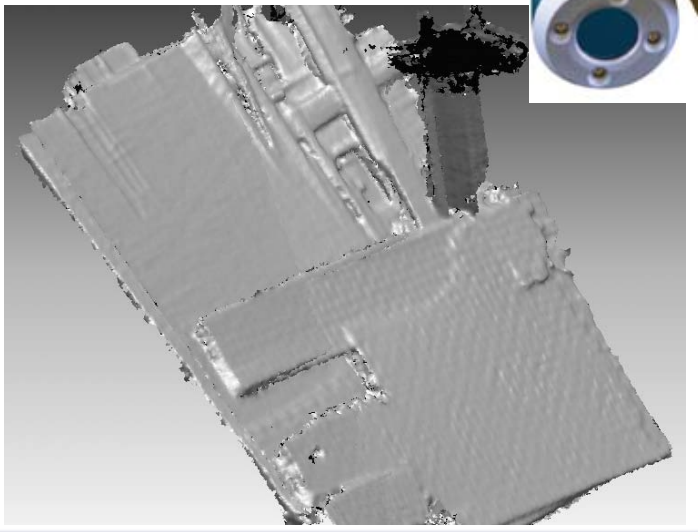


Courtesy – Doyle Hall

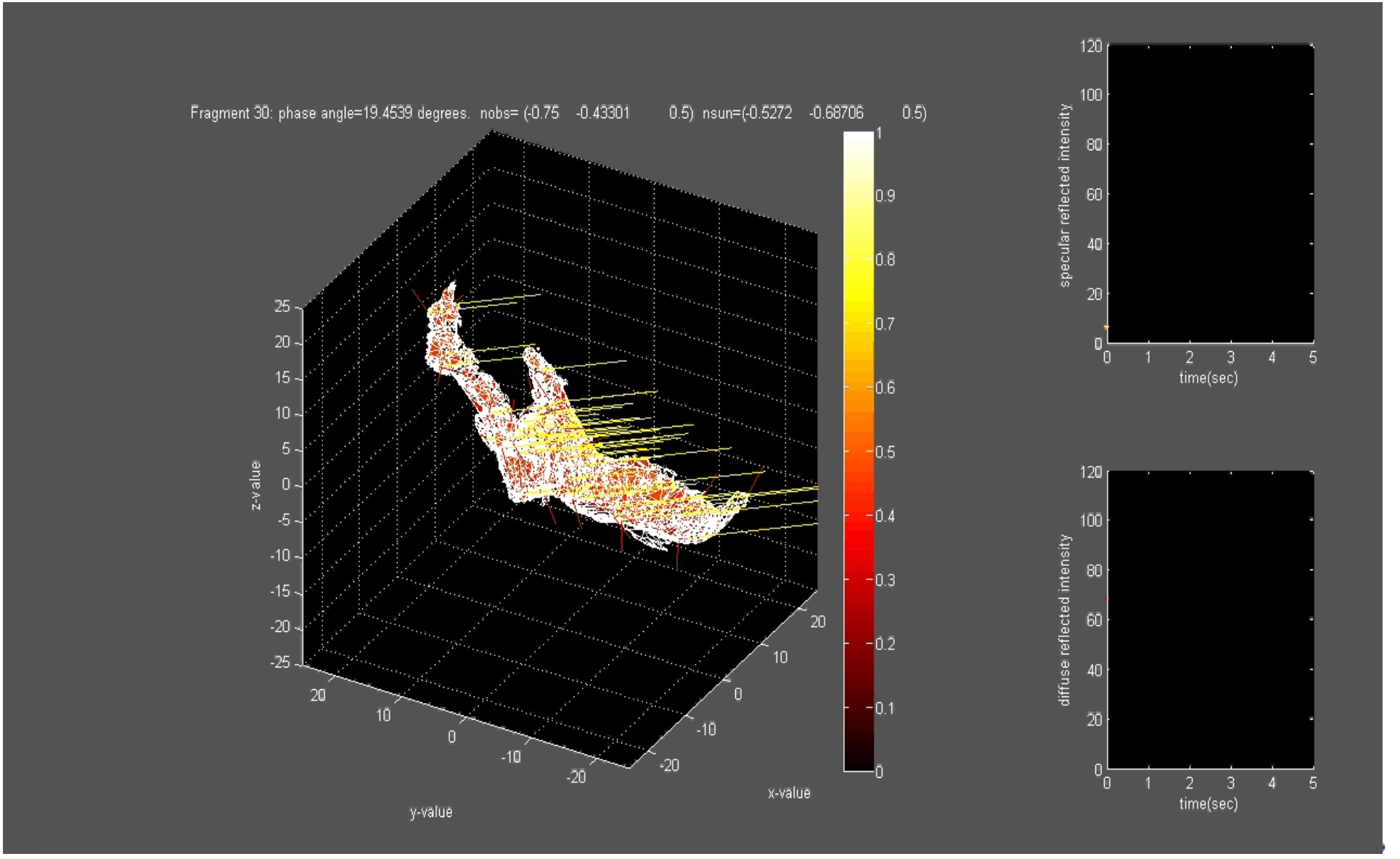
Optical Size and Shape Determination

- **Debris objects will have much more complex shapes**
- **Using handheld 3-dimensional scanner to digitize realistic debris shapes from ground hypervelocity impact tests**
- **Once digitized, can be manipulated in four dimensions**
  - 2 dimensions to orient body
  - Sun direction
  - Observer direction
- **Calibrate brightness and phase function with laboratory measurements**



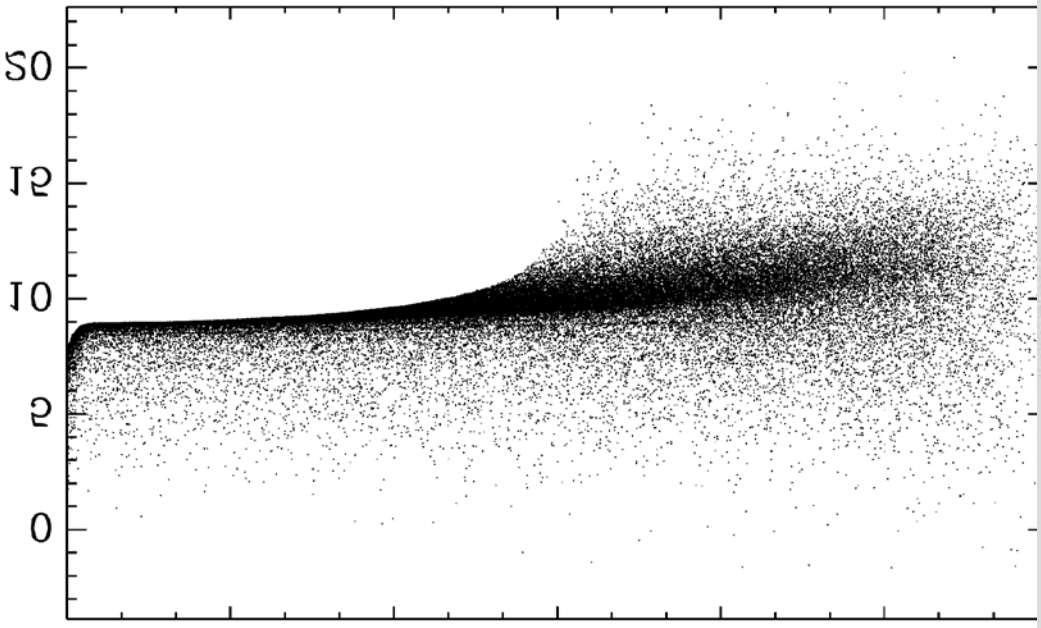


Computer Generated Light Curves from Scanned Fragments

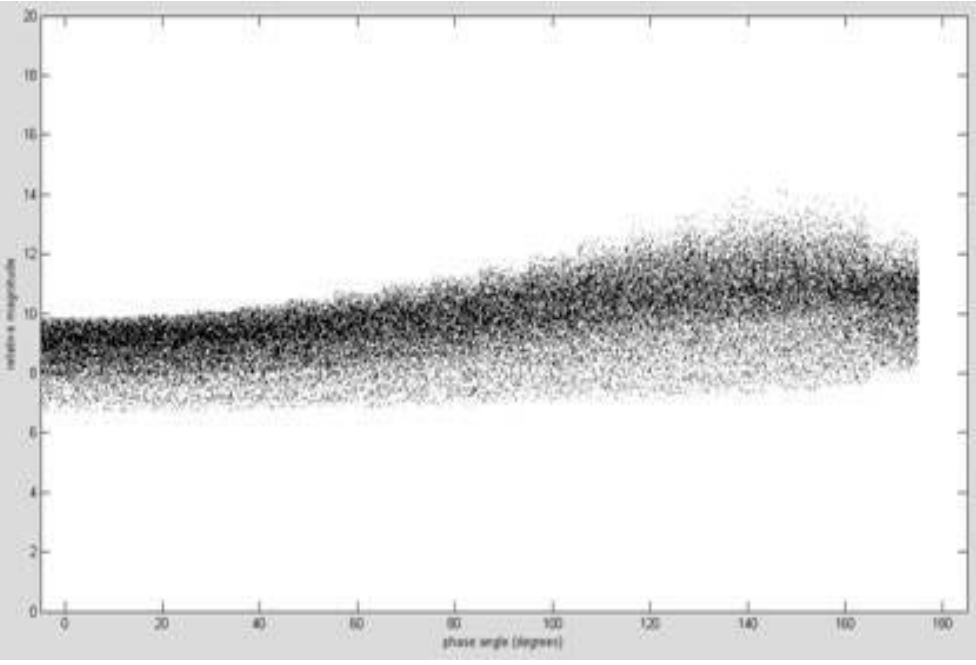


Optical Shape Analysis

Cube



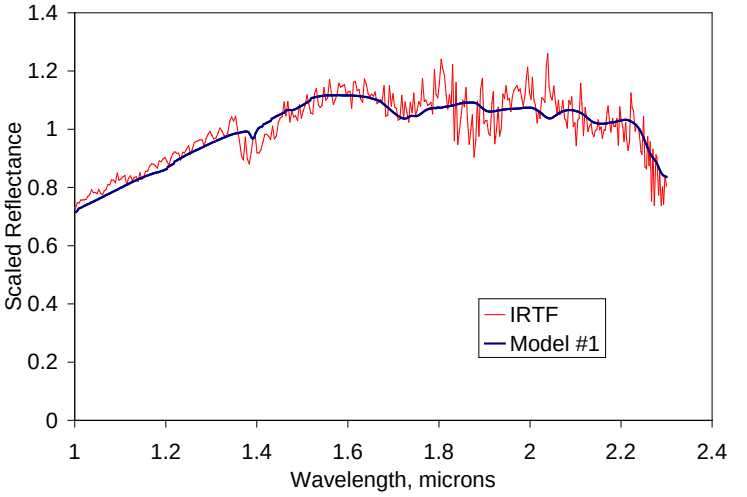
Flake

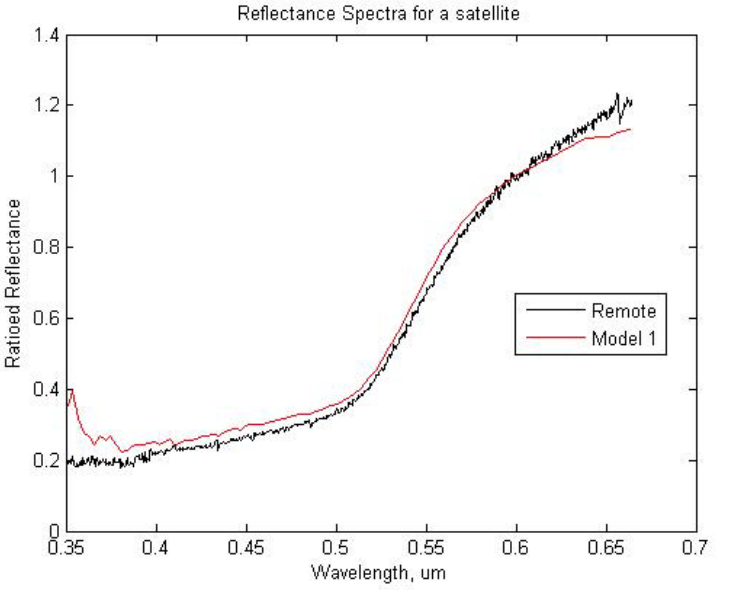


Left image courtesy – Doyle Hall

Spectral Studies

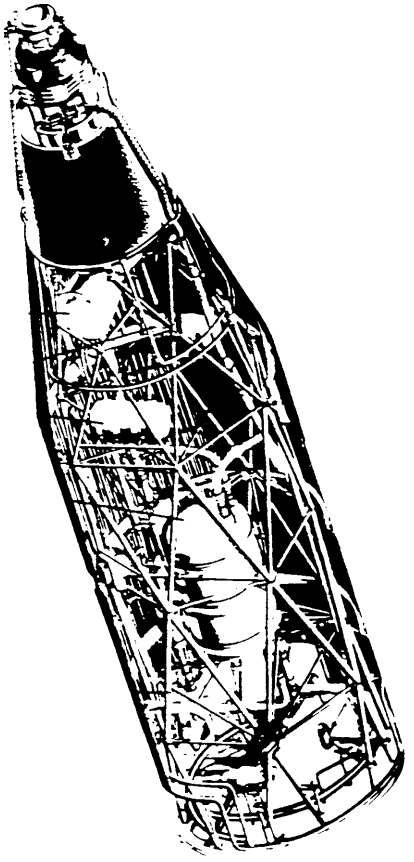
- **Use reflectance spectroscopy in the visible and near-infrared to determine the surface material of space objects**
  - Database of ground measurements using common spacecraft materials
- **Each material has specific absorption features that make it unique**
  - Using those features, as well as slope, creates a model for materials that best fits the spectrum taken of the object in space
- **Space weathering**
  - Measured pristine spacecraft prior to launch and looked at space weathering of materials
  - Many objects show a reddening on-orbit





Putting it all together - RORSAT Debris

Bouk Reactor



- **Peak @ 850-1000 km altitude is most dominant feature in the Haystack data**
- **Not seen by other sensors**
  - Few pieces larger than 3-5 cm - too small for SSN
  - No returned materials from these altitudes
- **Altitude distribution wrong for explosion/collision**
- **Sodium-Potassium (NaK) liquid metal coolant from Bouk reactors on Radar Ocean Reconnaissance SATellites (RORSATs) hypothesized**
- **Radar signature & polarization consistent with conducting spheres**
- **Optical signatures compatible with metallic spheres**
- **Optical albedo consistent with NaK**
- **Area-to-mass consistent with NaK**
- **Number consistent with available material**

Summary

- **Space Situational Awareness for debris – knowing all there is to know**
- **No single sensor or technique gives a complete picture**
  - **Can borrow from DoD 'Data Fusion' concepts**
- **Some success stories**
- **Just beginning to use advance techniques to better understand physical characteristics of debris**